SOUTH CAROLINA IRRIGATION GUIDE

CHAPTER 12. IRRIGATION WATER MEASUREMENT

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GENERAL

Reasonably accurate water measurement is necessary for proper design and evaluation of an irrigation system. The units of flow measurement commonly used for water are cubic feet per second (cfs) and gallons per minute (gpm).

The following equivalents may be found useful:

1 gallon (gal) = 231.02 cubic inches = 0.1337 cubic feet

1 gallon of water weighs 8.33 pounds

1 million gallons = 3.0689 acre-feet

1 cubic foot (cu ft) = 1,728 cubic inches

= 7.48 gallons

1 cubic foot of water weighs 62.4 pounds

1 acre-foot (ac-ft) = amount required to cover one acre one foot deep

= 43,560 cubic feet

= 325,828.8 gallons

= 12 acre inches

1 gallon per minute (gpm) = 0.00223 cubic feet per second

= 1,440 gallons per day (24 hrs)

1 million gallons per day (mgd) = 1.547 cfs

= 694.44 gpm

1 cubic foot per second (cfs) = 7.48 gallons per second

= 448.8 gpm

= 646,272 gpd

= 0.992 acre-inch per hour

= 1,983 acre feet per day (24 hrs)

It is common practice in planning to round off certain conversion factors such as:

1 cfs = 450 gpm
= 1.0 acre-inch per hour
= 2.0 acre-feet per day

Many methods of water measurement have been used in different situations for different purposes. The methods herein discussed will be as follows:

(1) methods of measuring small irrigation streams, (2) methods of measuring pipe flow, and (3) methods of measuring channel flow.

METHODS OF MEASURING SMALL IRRIGATION STREAMS

VOLUMETRIC

Volumetric flow measurements are made by measuring the time required to fill a container of known volume.

$$Q\ (\text{gpm}) = \frac{\text{Volume of water (gal)} \times 60}{\text{Time required to fill container (seconds)}}$$

Refer to NEH 15, pages 9-3 to 9-5.

SUBMERGED ORIFICE PLATES

The submerged orifice plate is placed across the furrow and the head loss through the orifice is measured under submerged conditions. See Figure 12-1.

Orifice plates consist of small sheet iron, steel, or aluminum plates that contain accurately machined circular openings or orifices usually ranging from 1 to 3½ inches in diameter.

In use, an orifice size is selected so as to produce a head differential within the 0.50 to 2.5 inch range, and the plate is placed in and across the furrow with its top as nearly as level as possible. Flow through the orifice must be submerged.

Flow through the orifice is calculated by the standard orifice formula:

$$\text{Discharge} = Ca\ (2\ gH)^{\frac{1}{2}}\ \ (\text{Cfs})$$

where H is head differential in feet, A is area in square feet, and g is gravitional acceleration. The formula can be written in terms of gallons per minute as

$$Q = 7.22\ Ca(h)^{\frac{1}{2}}$$

Where Q = discharge in gpm

C = coefficient of discharge (use 0.60 for approximate value)

h = head differential in inches

a = area in square inches

See NEH 15, pages 9-5 to 9-7 for more information.

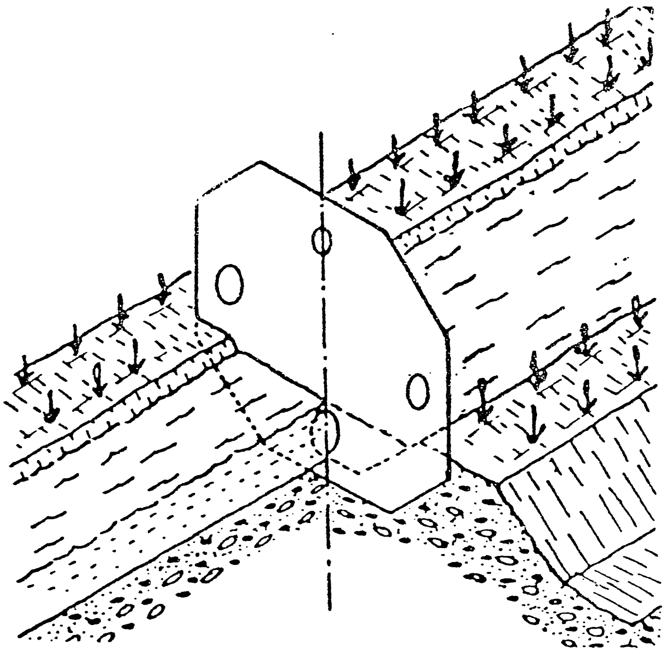

Figure 12-1. Submerged Orifice Plate

WASHINGTON STATE COLLETE (WSC) FLUME

The WSC measuring flume, developed at the Washington State College, adapts the Venturi principle to the measurement of flow in small channels. This flume consists of four principle sections: An entrance section upstream, a converging or contracting section leading to a constricted section or throat, and a diverging or expanding section downstream (Figure 12-2). The bottom of the flume is placed level, both longitudinally and transversely, at a height equal to or slightly higher than the channel bottom. Only one reading on the slanting scale is required. This reading is readily converted to gallons per minute by the use of tables. See NEH 15, Chapter 9, pages 9-10 to 9-12 for more information.

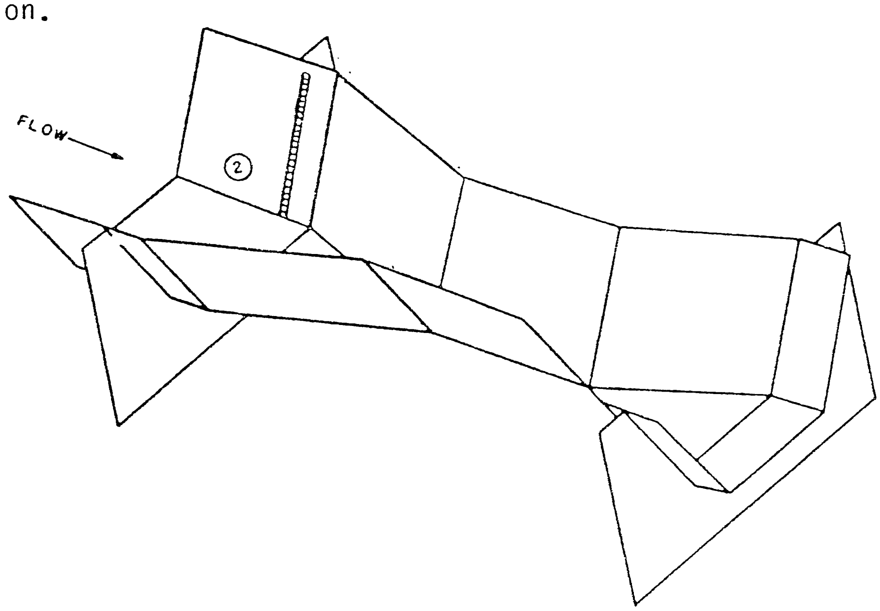

Figure 12-2. WSC Flume

SIPHON TUBES

Siphon tubes, used to remove water from a head ditch and distribute it over a field through furrows, corrugations, or borders, are also used to measure the rate of flow into these distribution systems.

These tubes, made of aluminum, plastic, or rubber, are usually preformed to fit a half cross section of the head ditch. The normal diameter range is from 1 to 6 inches, although both smaller and larger sizes are available. The smaller sizes are used with furrows and corrugations and the larger sizes with borders. Various lengths are available.

See NEH 15, Chapter 9, pages 9-10 to 9-14 for more information.

METHODS OF MEASURING PIPE FLOW

PIPE ORIFICES

Pipe orifices are usually circular orifice plates placed within or at the end of a circular pipe (see Figure 12-3). The head on the orifice is measured with a manometer. A manometer is a device that measures the pressure differential in feet of water or inches of mercury. The orifice is often used for well discharge measurement from wells in a range of 50 to 2000 gpm. Discharge through the orifice is computed by the formula:

$$Q = 7.22\ Ca(h)^{\frac{1}{2}}$$

where Q = Discharge in gpm

C = Coefficient of discharge (See Fig. 9-8, Section 15, Chapter 9, NEH)

a = cross sectional area of the orifice in square inches

h = head on the orifice in inches measured above the center for free flow.

For discharge tables refer to NEH 15, Chapter 9, Table 9-5.

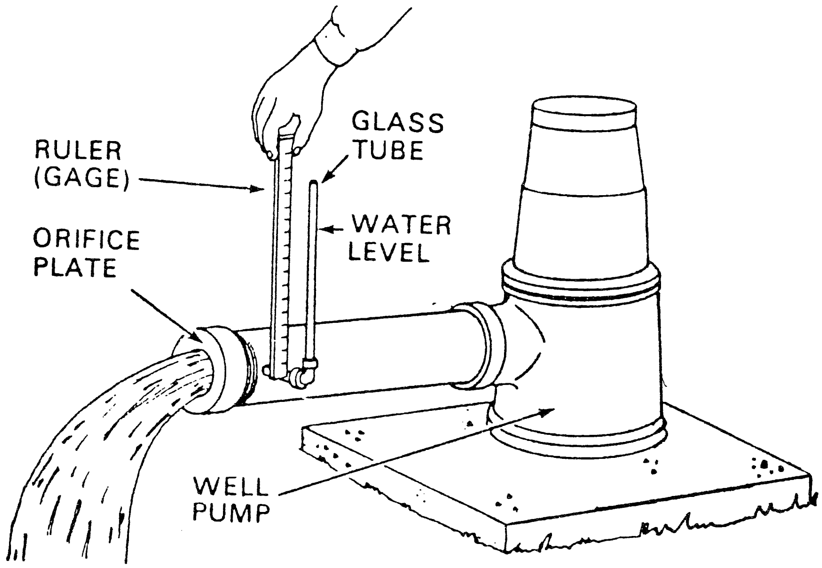

Figure 12-3. Pipe Orifice

VENTURI METERS

The Venturi meter measures the flow in a pipe under pressure. It utilizes the Venturi principle in that flow passing through a constricted section of pipe is accelerated and its pressure head lowered. With the relative cross sectional areas known the flow is measured by measuring the drop in pressure. For further information, refer to pages 9-17 to 9-20, Section 15, Chapter 9, NEH (see Figure 12-4).

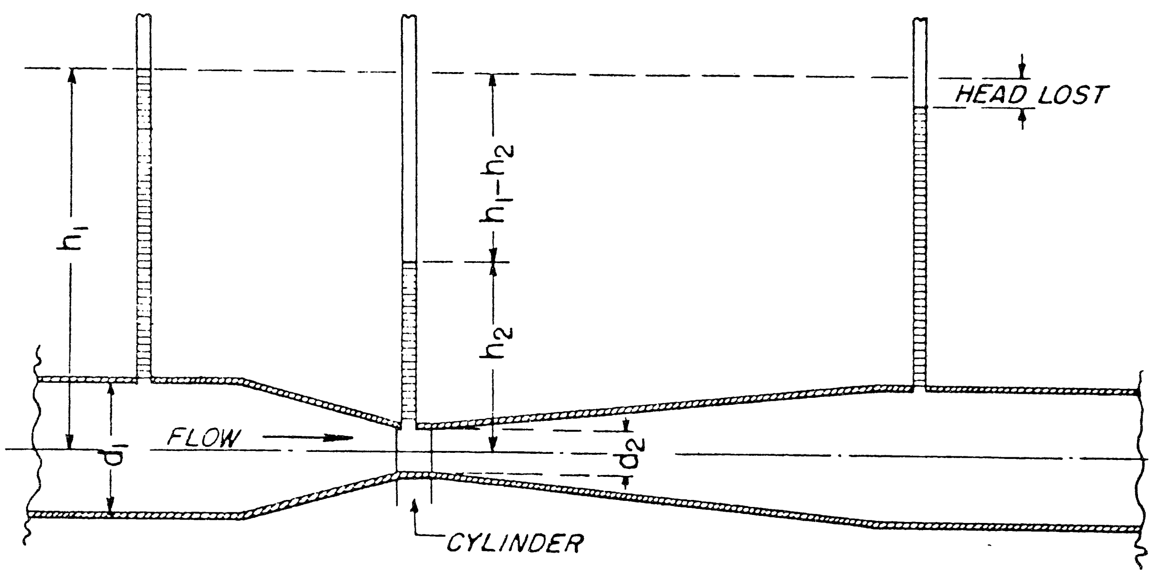

Figure 12-4. Venturi Meter

IRRIGATION FLOW METER

Meters of this type are generally of the velocity type. They essentially consist of a conical propeller connected to a registering head by a gear train (see Figure 12-5). They are operated by the kinetic energy of the flowing water. Three basic types are mainly used: (1) low-pressure line meters, (2) open-flow meters, and (3) vertical-flow or hydrant-type meters. Flow tables and charts are available from each company making the device.

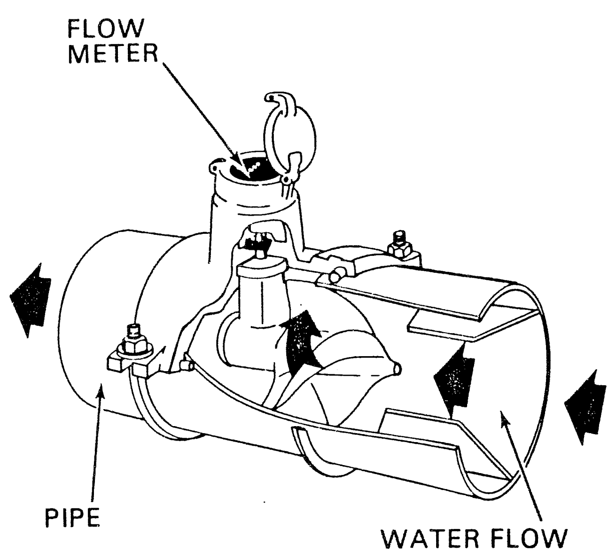

Figure 12-5. Irrigation Flow Meter

COORDINATE METHOD

In a coordinate method, coordinates of the jet issuing from the end of a pipe are measured (see Figure 12-6). The flow from the pipe can be measured whether the pipe is discharging horizontally or vertically. They should be used only where facilities for more accurate measurement are not available, and where an error of up to 10% is permissible. Refer to pages 9-24 through 9-28 of Section 15, Chapter 9, of the NEH of procedures and tables.

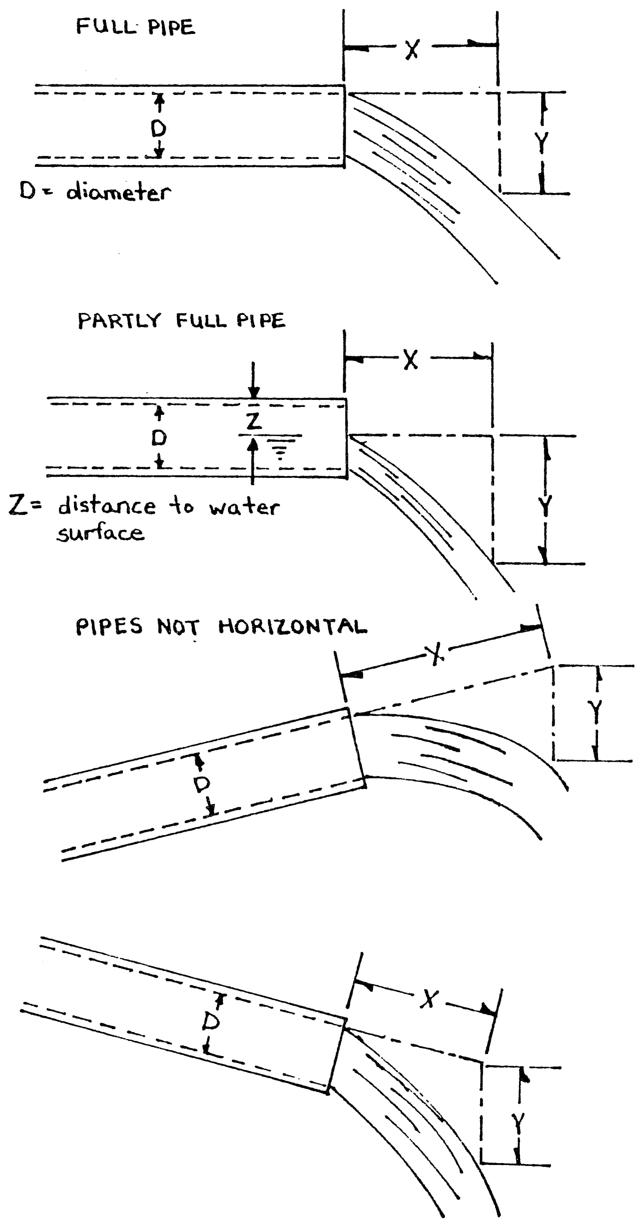

Figure 12-6. Coordinate Method

FLOAT METHOD

The flow rate can be estimated by timing the passage of a small float through a measured length of channel. The procedure for estimating rate of flow by the float method is as follows:

1. Select a straight section of ditch with fairly uniform cross sections. The length of the section will depend on the current, but one hundred feet usually will be adequate. A shorter length may be satisfactory for slow flowing ditches.

2. Make several measurements of depth and width within the trial section, to arrive at the average cross section area. The area should be expressed in terms of square feet (see Figure 12-7).

3. Place a small float in the ditch a known distance upstream from the upper end of the trial section. Determine the number of seconds it takes for the float to travel from the upper end of the trial section to the lower end. Make several trials to get the average time and travel. The best floats are small rounded objects which float nearly submerged. They are less apt to be affected by wind or to be slowed by striking the side of the channel. Among small objects which make good floats are a long necked bottle partly filled with water and capped, a rounded block of wood, or an orange. A wooden sphere, like a croquet ball, is excellent.

4. Determine the velocity (or speed) of the float in units of feet per second by dividing the length of the section (in feet) by the time (in seconds) required for the float to travel that distance.

5. Determine the average velocity of the stream. Since the velocity of the float on the surface of the water will be greater than the average velocity of the stream, the float velocity must be multiplied by a correction coefficient to obtain a good estimate of the true average stream velocity. The correction factor varies with the type of float used with the shape and uniformity of the channel. With floats that sink only an inch or two below the water surface, a coefficient of about 0.80 should be used for most unlined farm ditches. A coefficient of 0.85 is appropriate for smooth uniform lined ditches. With floats that extend two-thirds or more of their depth below the surface, the coefficients should be about 0.85 for unlined ditches and 0.90 for lined ditches (see Figure 12-8).

Station 0+00

Distance from left water edge	(ft.)	0.0	1.5	3.6	5.0
Water depth	(ft.)	0.00	1.10	1.15	0.00

$$\text{Area} = \frac{1.10 \times 1.5}{2} + \frac{(1.10 + 1.15)}{2} 2.1 + \frac{1.15 \times 1.4}{2}$$

$$= 0.82 + 2.36 + 0.81 \qquad = 3.99$$

Station 0+40

Distance from left water edge	(ft.)	0.0	1.3	3.8	5.2
Water depth	(ft.)	0.00	0.85	1.05	0.00

$$\text{Area} = \frac{0.85 \times 1.3}{2} + \frac{(0.85+1.05)2.5}{2} + \frac{1.05 \times 1.4}{2}$$

$$= 0.55 + 2.37 + 0.73 \qquad = 3.65$$

Station 0+90

Distance from left water edge	(ft.)	0.0	0.9	1.9	3.3	4.8
Water depth	(ft.)	0.00	0.80	1.15	1.15	0.00

$$\text{Area} = \frac{0.80\text{x}0.9}{2} + \frac{(0.80+1.15)}{2} + \underline{1.15\text{x}1.4} + \frac{1.15\text{x}1.5}{2}$$

$$= 0.36+0.98+1.61+0.86 \qquad = 3.81$$

+

11.45

Average cross section area = $\frac{11.45}{3}$ = <u>3.82 square feet</u>

Figure 12-7. Typical Cross Section Data for Float Method

6. Compute the rate of flow. The rate of flow is obtained by multiplying the average cross sectional area (Item 2) by the average stream velocity (Item 5) (see Figure 12-8). The accuracy of these estimates of flow rates is dependent upon the preciseness with which average cross sectional areas and float velocities have been determined and upon the selection of the proper correction coefficient.

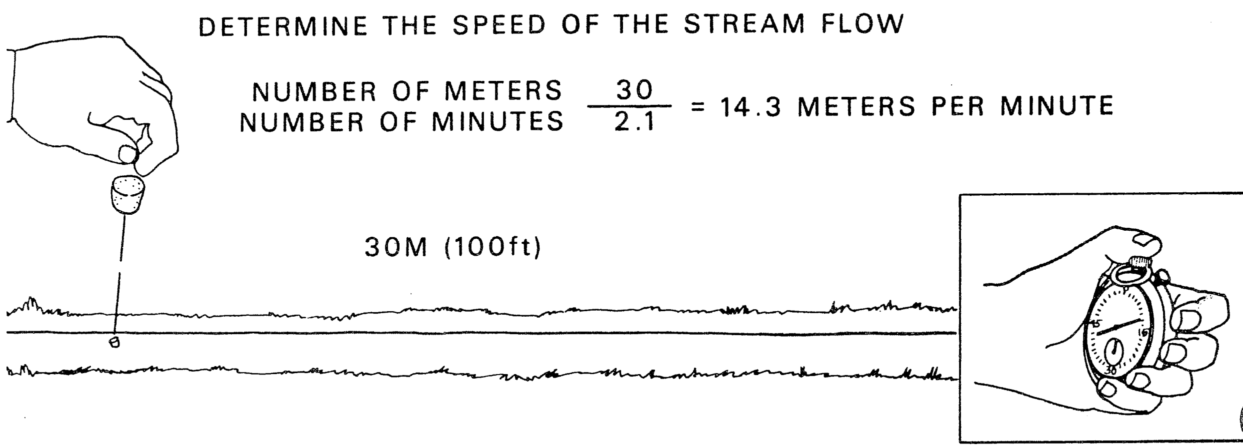

Figure 12-8. Computing Channel Flow

SUBMERGED ORIFICE

A submerged orifice is a hole in a bulkhead through which water flows under submerged conditions. The opening of a standard submerged orifice is sharp edged and usually rectangular with a width 2 to 6 times the height. They can be used in channels having grades which may be too flat for weir operation. The forumla used is the same as for pipe orifice:

$$Q = ca\sqrt{2gh}$$

where c = 0.61 for orifices with complete contraction.

Refer to pages 9-63 to 9-65, Section 15, Chapter 9, NEH for installation procedures and flow tables.

GATES

Gates can be arranged and calibrated to operate as a type of submerged orifice. The same pipe orifice formula applies:

$$Q = ca\sqrt{2gh}$$

The c value here will be a variable depending on the nature of the specific gate opening. When the discharge is free, the head (h) is the difference in elevation between the upstream water surface and the center of the gate. Figure 9-33, Section 15, Chapter 9, NEH gives an illustration and flow chart for a commercial meter gate.

WEIRS

A weir notch is one of the simpler water measuring devices to use and construct (see Figure 12-9). There are three general types depending on the shap of the notch: (1) rectangular, (2) trapezoidal of Chipolletti, and (3) 90° triangular. They require considerable loss of head, often not available in ditches on flat grades. Triangular weirs give the most accurate readings on flows of less than 1 cfs. Rectangular and trapezoidal flumes are used to measure discharges up to 75 cfs or more. Refer to NEH, Section 15, Chapter 9.

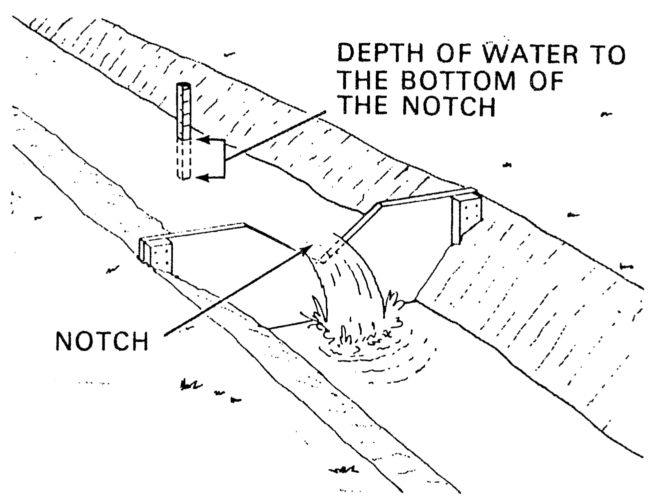

Figure 12-9. Weir Notch

FLUMES

There are three major types of flumes used to measure irrigation water: (1) Parshall (see Figure 12-10), (2) trapezoidal, and (3) cutthroat. They all operate similarly and require less operating head than weirs. They all have a converging or contracting section, a constricted section or throat, and a diverging or expanding section. The ARS cast-in-place, 2-foot concrete trapezoidal flume was designed for use in trapezoidal irrigation canals flowing up to 50 cfs.

The cutthroat flume was developed as a portable flume, although it can be permanently installed, for flows up to 10 cfs. The Parshall is generally a permanently installed flume and used to measure flows up to 100 cfs or more. Refer to NEH, Section 15, Chapter 9, for Parshall flume. Refer to USDA-ARS Technical Bulletin No. 1566 for the cast-in-place trapezoidal flume and for the cutthroat flume.

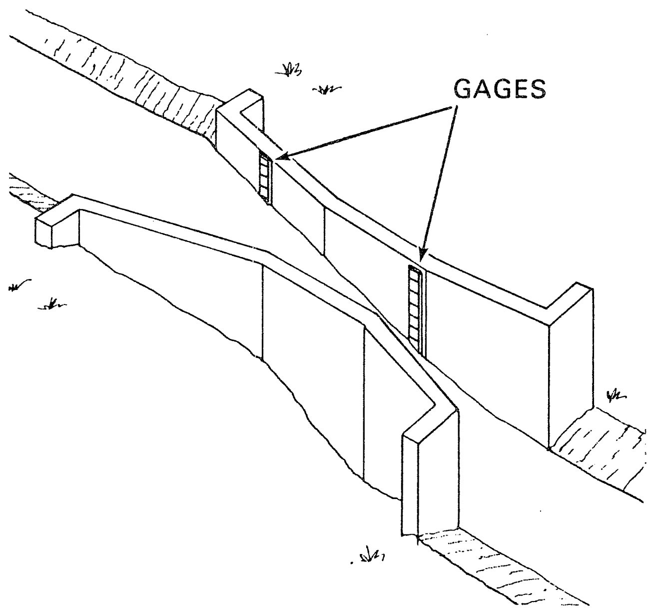

Figure 12-10. Parshall Flume

CURRENT METERS

The current meter is similar to the flow meter in that it measures the velocity of flow by means of propeller. The RPM of the propeller is usually measured by counting the breaks in an electric circuit while listening through headphones, and using a stop watch. They are either suspended from cables over a channel or mounted by rods and carried by hand through the channel. Current meters are rated by the manufacturer, and a rating table is furnished. Measurements are usually taken every 2 to 10 feet across the channel depending on the width of the channel. Readings are commonly taken at 0.2 and 0.8 of the depth measured from the water surface. The average of these two values is the average velocity in depth. For further details refer to pages 9-28 through 9-30, Section 15, Chapter 9, of the NEH.

Culvert Method

If a culvert is near the area where a flow measurement is needed, the velocity can be determined by the float method discussed on page 12-8 using the appropriate coefficients for lined ditches.

The flow is determined by use of the following chart:

HYDRAULIC PROPERTIES OF CULVERTS FLOWING PARTIALLY FULL

	d' (Depth factor)	a' (Area of Flow Factor)		d' (Depth factor)	a' (Area of Flow Factor)
Full	1.0	0.7854	Half	0.5	0.3927
	0.95	0.7708		0.4	0.2934
	0.9	0.7445		0.3	0.1981
	0.8	0.6735		0.25	0.1536
	0.7	0.5874		0.2	0.1118
	0.6	0.4920		0.1	0.0408
			Empty	0.0	0.0

Adapted From Handbook of Culvert and Drainage Practice 1947

Depth factor (d') is expressed as depth of flow in culvert divided by culvert diameter (D). $d' \text{ (in table)} = \frac{\text{Depth of flow}}{\text{Diameter (D)}}$

Measure depth of flow at both ends and use average depth in calculations.

Multiplying area of flow factor (a') by the pipe diameter squared $(D)^2$ for the corresponding depth of flow.

Multiply this area by the velocity in feet per second to obtain flow in CFS.

Example Problem - Determine culvert flow.

Given: Average velocity in a 2.0 foot diameter culvert is estimated to be 2.0 ft/sec.
Average measured depth of flow in the culvert = 1.5 ft.

Solution: $d' = \frac{\text{Depth of flow}}{D} = \frac{1.5}{2} = 0.75$

Interpolating from chart: $a' = \frac{.6735 + .5874}{2} = 0.63$

Area of flow $= a'D^2 = 0.63(2)^2 = 2.52$ sq. ft.

Culvert Flow $= 2.52(V) = 2.52(2) = \underline{\underline{5.0 \text{ cfs}}}$